A Concept for Ant-routing with Colored Pheromones in Wireless Mesh Networks

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Abstract—**Different classes of traffic pose different requirements on the underlying network. For example, VoIP traffic has stricter requirements on delay and jitter than background traffic such as file downloads. Ant-routing algorithms store an amount of pheromone proportional to the measured "goodness" of a link in the network. This approach assumes that a) links have only one dimension of "goodness" and b) that "goodness" is equal for all types of traffic. In reality, though, links can have several orthogonal dimensions of "goodness". In addition to bandwidth, delay, and jitter wireless links also experience changes of bandwidth over time and varying amounts of packet loss. Therefore, a route in a wireless mesh network may be suitable for one class of traffic but unsuitable for another. The proposed algorithm addresses this problem by introducing "colored pheromones" which are matched to the traffic classes. Depending on the measurement of the different dimensions of "goodness" and their match to the traffic classes an ant will deposit an apropriate amount of pheromones in the adequate "color" in the routing tables. Traffic will then follow the appropriately colored paths.**

Index Terms—**Wireless Mesh Networks, Ant Algorithm, Routing, Colored Pheromones**

I. Introduction

We assume an 802.11b/g based WMN (Wireless Mesh Network) which is used as an access network to the Internet. In this case, the network has to deal with IP traffic as it occurs on the Internet. With the advent of VoIP (Voice over IP) and real-time traffic many approaches to better support the quality of service requirements of these different types of traffic have been developed as shown eg. in [1], [2], [3].

In the wireless world, the problem of supporting different types of traffic is compounded by smaller bandwidths (compare standard 802.11g specified at a maximum netto rate of 54 MBit/s while 1 GBit/s is becoming common in the wired world) and higher amounts of jitter and delay due to retransmissions and MAC overhead.

Furthermore, bandwidth, jitter and delay can change dramatically over time, eg. through rate adaptation and depend very much on the channel quality of the link [4]. Therefore, it becomes even more important to support different types of traffic.

Ant-algorithms have been proposed as a routing algorithm [5] and in specific for wireless networks in [6], [7], [8], [9], but these works use only one color (or dimension) of pheromones. The In [10] the CAS (Colored Ant System) introduces "multicolored pheromones" to solve a graph coloring problem and distribute agents to clusters of nodes. The MACO (Multiple Ant-Colony Optimization) approach [11], [12] uses multiple ant colonies – each using their own pheromone color – to mitigate the problems of stagnation and to increase adaptivity of the algorithm but does not use traffic classes. ARAMA (Ant Routing Algorithm for Mobile Ad hoc networks) [9] makes an attempt to account for different dimensions of "goodness" but does not treat possibly orthogonal requirements separately and uses only one color of pheromones. The most similar work is by Labella and Dressler [13] who implement colored pheromones for division of labor between nodes in Sensor/Actuator Networks (SANET)

We propose an extension to the AntHocNet algorithm proposed in [6] and partly inspired by ARAMA [9]. Based on the insight that traffic can be grouped into different classes [1] our algorithm introduces "colors" which correspond to the different traffic classes (see Section II). An overview of the algorithm is given in Section III. Ants evaluate paths for suitability for a certain class of traffic and mark them with pheromones in the appropriate color (Section IV). Traffic is then routed according to its class requirements by simply following the appropriately colored paths as shown in Section V. The paper is concluded with a description of initialization details in Section VI and conclusion and future work in Section VII.

II. Traffic Classes and Colors

We assume that the WMN is used as an access network to the internet. Analogous to [1] we group traffic into four classes:

- **Conversational**, such as VoIP or video conference traffic
- **Streaming**, where a play-out buffer can mitigate the effects of jitter and where no interaction takes place; eg. watching a video stream or listening to a pod-cast.
- **Interactive** with lower bandwidth requirements such as Web surfing and Web applications.
- **Background**, such as Email and large File transfers (eg. ftp or P2P-Filesharing).

Table I shows the traffic classes and their requirements in terms of network QoS. To support the requirements of these traffic classes, we introduce the notion of "color" to the concept of pheromones in our Ant-algorithm.

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TABLE I
TRAFFIC CLASSES AND REQUIREMENTS

Class	Name	Critical	Uncritical
1	Conversational	Bandwidth, jitter, delay	-
2	Streaming	Bandwidth	Jitter, Delay
3	Interactive (Web)	Delay	Jitter, (Bandwidth)
4	Background (Data)	-	Jitter, delay, (Bandwidth)

Different traffic classes and their differing critical and uncritical requirements.

We choose four colors which we name A, B, C, and D. The mapping of these colors to the traffic classes is shown in Table II.

TABLE II
MAPPING OF COLORS TO TRAFFIC CLASSES

Color	Class	Name
A	1	Conversational
B	2	Streaming
C	3	Interactive (Web)
D	4	Background (Data)

Each traffic class is associated with a certain "color". Colors are named A, B, C, D for easier reference in black and white documents.

Like in other Ant-routing algorithms, the ants mark paths in the network by depositing pheromones at each node along the way, thereby marking a "trail" along which data traffic can then be routed. In the colored pheromone approach, the ants mark the paths through the network by depositing pheromones with different colors depending on the suitability of the path for the corresponding traffic classes. For this, the algorithm uses information gained from MAC-layer measurements (details see below). Eg. a path with high bandwidth, low jitter, and low delay is suitable for traffic in the Conversational class and would therefore be marked with pheromones of color "A".

We further define that traffic can use paths marked with a color other than its own if no path of appropriate color can be found. Eg. if all paths are of such high quality that they are all marked with color "A", then traffic of classes 2, 3, and 4 can also use these "A-paths". I.o.w., traffic can use a path that is "better than necessary" if no other suitable path is found. Note that traffic should preferably be routed along its major color so that traffic with lower requirements does not block the path of traffic with higher requirements. Fig. 1 shows the mapping of traffic classes to paths including possible alternative colors.

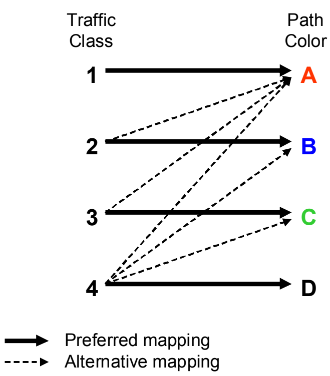

Fig. 1. Mapping of Traffic Classes to Alternative Color Paths.

III. ALGORITHM

A. Overview

The algorithm has three parts:

- **Pro-active part:** first during initialization and later at regular intervals *Forward Ants* (FAs) are started to search for paths to destination nodes (see Fig. 2).
- **Re-active part:** when traffic must be sent to a destination for which no route is known, the algorithm starts a *Forward Ant* to search for a path on demand (Fig. 2).
- **Traffic sending and mainenance part:** since the network is used as an access network to the Internet, it can safely be assumed that after initialization most of the time there will be traffic on the network. We further assume that the majority of this traffic is made up of TCP traffic which sends acknowledgements (ACKs). Therefore, this traffic may be used to piggy-back exploiting *Forward Ants* onto data packets and *Backward Ants* (BAs) onto TCP ACKs to save overhead (Fig. 3). Exploiting vs. exploring *Forward Ants* are described in Subsection III.C.

Fig. 2 below shows the pro-active part and the re-active part of the algorithm. Both start by sending a *Forward Ant* (FA). In the case of the pro-active part the *Forward Ant* is started at regular time intervals while the re-active part starts an *Forward Ant* if data traffic needs to be sent to a destination for which no route is known. In this case the route is built on-demand.

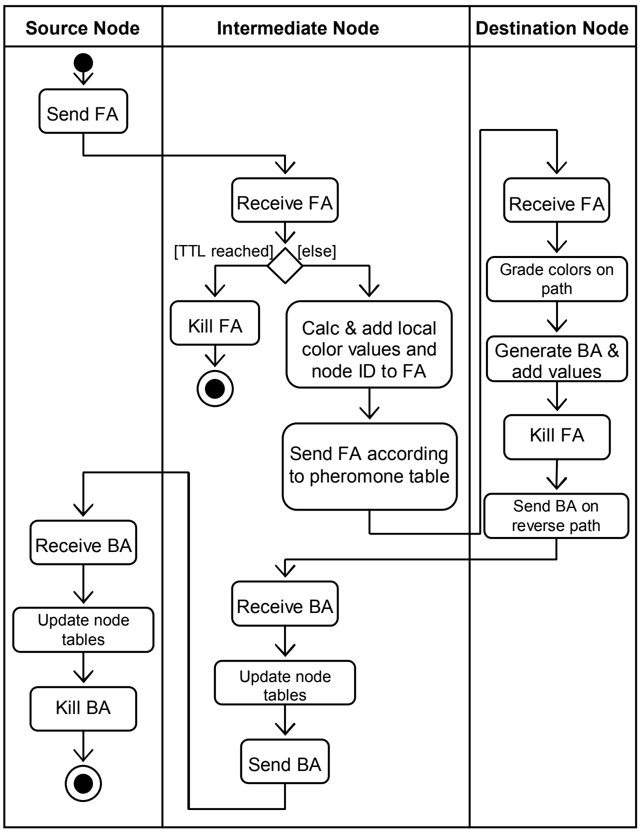

Fig. 2. UML Activity Diagram for pro-active and re-active parts of the algorithm, FA … Forward Ant, BA … Backward Ant. Note that the ant can travel via several intermediate nodes but for clarity only one is shown.

In both cases the *Forward Ant* is started at the source node and sent according to the values in the pheromone table. When it is received by an intermediate node and its time to live (TTL, expressed in number of hops) is reached the ant is killed. I.o.w. the ant did not find a viable path. In this case the route search is continued with the next ant. If the ant's TTL is not yet reached it calculates the color values for the next hop based on MAC layer measurements at the node. The values are stored in the ant and it is then sent on according to the values in the pheromone table. When the ant eventually reaches the destination node the path is graded, a *Backward Ant* (BA) is created and the path grade is stored in the *Backward Ant*. The *Forward Ant* expires and the *Backward Ant* is sent back to the source node on the reverse path. When the *Backward Ant* is received by a node it updates the local pheromone tables according to the path grade and is sent on until it reaches the original source node where it expires.

The maintenance and traffic sending part of the algorithm is shown in Fig. 3. When a node has TCP traffic to send to a destination for which a path is known it is possible to avoid sending pro-active ants for this path. Rather, these ants can be piggy-backed onto the traffic. Traffic and *Forward Ant* are then sent using the best suited path (which depends on the traffic class and the color of the path). When it is received by an intermediate node the local color values are calculated as in the pro-active part and the *Forward Ant's* values are updated. It is then sent on using the best suited path.

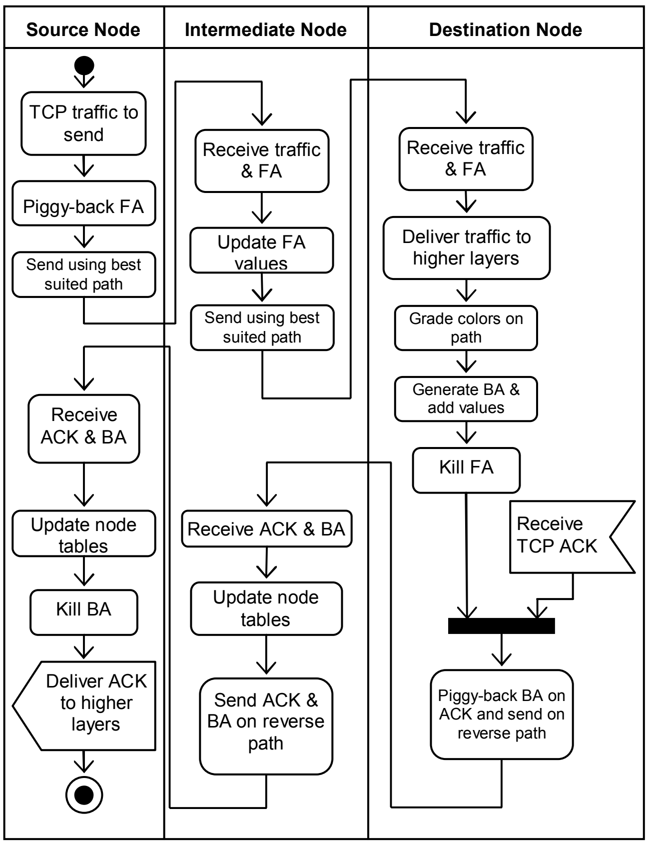

Fig. 2. UML Activity Diagram for Maintenance Part of the algorithm, FA … Forward Ant, BA … Backward Ant. Note that the ant can travel via several intermediate nodes but for clarity only one is shown.

When traffic is received at the destination node, the traffic data is delivered to the higher layers in the network stack. The path is graded, a *Backward Ant* is created, the path grade is added to the *Backward Ant* and the *Forward Ant* is killed. Depending on the TCP window size, the node has to wait until a TCP ACK is received from the higher layers in the network stack on which the *Backward Ant* can be piggy-backed on. If more than one *Forward Ant* is received during the wait the values of the newest *Forward Ant* are used and the old values are updated in the *Backward Ant* on hold. When the TCP ACK is received, the *Backward Ant* is piggy-backed and sent on the reverse path back to the source node. Analogous to the pro-active and re-active part it is then sent on until it arrives at the source node, updating the node pheromone tables along the way.

B. Link Selection

When an ant is to be sent as described above ("send FA according to pheromone table" in Fig. 2) the next hop is chosen with probability $P_{n,d}$ according to the transition rule

$$P_{n,d} \sim \frac{\tau x_{n,d}^{i}}{\sum_{j \in N_d^i} \tau x_{j,d}^{i}} \qquad (1)$$

where

- i … the current node
- n … the next node
- d … the destination node
- $\tau x_{n,d}^{i}$ … the pheromone value for a certain color for the link from node i to node n with intended destination d, eg. $\tau A_{n,d}^{i}$ the pheromone value for color *A*.
- N_d^i … the set of neighbors of node i which know a path to destination d.

The pheromone color x of τx is randomly chosen as one of *{A, B, C, D}* when the first link is taken; after the first link the color of the current ant is determined and stays fixed for the lifetime of the ant. While the ant still continues to collect information about the other color values it will only search for a path of the color it has been assigned.

C. Exploiting Ants vs. Exploring Ants

Since the transition rule in (1) defines a probability distribution there is a certain probability that an ant will not choose the best path and thus become an exploring ant. Whereas exploiting ants reinforce existing paths exploring ants try to find new alternative paths. The exploring ant records all color values encountered on the path. When it reaches the destination node it grades the path for each color separately and creates a *Backward Ant*. The *Backward Ant* updates the pheromone tables for all colors accordingly on its way back to the source.

IV. PATH GRADING AND PHEROMONE UPDATING

A. Measuring "Goodness" and Grading a Path

To measure the "goodness" of any given path nodes keep running averages of MAC-layer measurements of the link's bandwidth, jitter, and delay.

We define a function

$$f_{good} : \left\langle BW_{avg}, J_{avg}, D_{avg} \right\rangle \mapsto \vec{X} \qquad (2)$$

with BW_{avg} the average bandwidth, J_{avg} the average jitter, and D_{avg} the average delay on the link calculated using a sliding window average and

$$\vec{X} = \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix} \qquad (3)$$

the color vector for the current link taken. The color values *a*, *b*, *c*, and *d* are in the interval *[0; 1]* and are calculated using thresholds which map link attribute values (eg. a certain bandwidth) to percentage values of the color. This mapping may be implemented using a simple lookup table in the routing nodes and the thresholds can be fine-tuned by the network administrator. The color vector $\vec{X}$ is then stored in an ordered list $L_{ant} = \{\vec{X}_1, \vec{X}_2, ..., \vec{X}_n\}$ in the ant. Using a granularity of 1% for each color it is possible to encode these four values in 2 bytes per hop: at this granularity, each color can take one of 100 discrete values. By using the highest bit as a switch, two color values can be stored into one byte resulting in a total of two bytes for four color values.

When the ant reaches the destination node the path is graded for all colors by calculating the path grade

$$\vec{G}_P = \prod_j \vec{X}_j \qquad \forall \vec{X}_j \in L_{ant}. \qquad (4)$$

By element-wise multiplication of the color vectors as

$$\vec{G}_P = \begin{pmatrix} a^* \\ b^* \\ c^* \\ d^* \end{pmatrix} = \begin{pmatrix} a_1 \\ b_1 \\ c_1 \\ d_1 \end{pmatrix} \circ \begin{pmatrix} a_2 \\ b_2 \\ c_2 \\ d_2 \end{pmatrix} \cdots \begin{pmatrix} a_n \\ b_n \\ c_n \\ d_n \end{pmatrix} \qquad (5)$$

where $\circ$ denotes element-wise multiplication so that $a^* = a_1 \cdot a_2 \cdots a_n$, $b^* = b_1 \cdot b_2 \cdots b_n$, $c^* = c_1 \cdot c_2 \cdots c_n$, and $d^* = d_1 \cdot d_2 \cdots d_n$. Thereby, the worst hop in the path is accurately reflected as being the path bottleneck.

B. Pheromone Table Updating

The path grade is then stored in the *Backward Ant* (BA) and used to update the pheromone values of the path as the *Backward Ant* travels back to the source node. Equation (6) shows the update function for a link that is on the path (ie. a hop $i \longrightarrow n$) of the *Backward Ant.*

$$\tau x_{n,d}^i(t) = \tau x_{n,d}^i(t-1) \cdot f_{evap} + g(Gx_P) \qquad (6)$$

Gx_P denotes that element of the path grade vector which matches the color of the pheromone being updated, f_{evap} the evaporation function and $g(Gx_P)$ the enforcement function, and *t-1* denoting "the last value". $\tau x_{n,d}^i$ and Gx_P are always used with identical values for *x*; eg. to calculate $\tau A_{n,d}^i$ a value of $GA_P = a^*$ is used.

For all other links not on the path (ie. a hop $i \longrightarrow m$, where $m \neq n \ \forall m,n$), the amount of pheromone is decreased as shown in (7).

$$\tau x_{m,d}^i(t) = \tau x_{m,d}^i(t-1) \cdot f_{evap} \qquad (7)$$

As shown in [9] examples of such functions may be $f_{evap} = 1 - Gx_P$ and $g(Gx_P) = Gx_P{}^K$ which results in $0 \leq f_{evap} \leq 1$ and $0 \leq g(Gx_P) \leq 1$ for $0 \leq Gx_P \leq 1$.

V. Traffic Sending and Path Maintenance

Traffic is always sent along the best suitably colored path found and *Forward Ants* are piggy-backed onto data packets. In this way, when the path becomes overloaded, its pheromone value will fall over time. Once it becomes worse than the second-best path traffic will automatically switch to the second-best path.

When no suitable path is found traffic may choose paths which are "better than necessary" according to the mapping in Table II.

When TCP traffic is sent, the *Backward Ant* is piggy-backed onto the TCP ACK. Therefore, depending on the current window size one *Backward Ant* will travel the reverse path of several *Forward Ants* just like one TCP ACK may acknowledge several TCP segments.

VI. Algorithm Initialization

When the algorithm starts the pheromone tables are initialized with equal values for all $\tau x_{n,d}^i$ resulting in an equal probability for each link to be chosen. The pro-active part of the algorithm is started and sends out periodic *Forward Ants* even if no traffic load is yet placed on the network.

VII. Conclusion and Future Work

We have presented a proposal for a new Ant-routing algorithm which supports traffic classes with orthogonal requirements on the link quality by the use of "colored pheromones". Color is used to mark different trails suitable to the different traffic classes. Traffic may use trails which are "better than necessary" if no trail of the appropriate color is found but preferably chooses a trail of the color assigned to its traffic class so as not to block good trails for higher-priority traffic.

Future work will include a simulation study of the proposed algorithm to fine-tune the algorithm parameters and evaluate performance.

VIII. ACKNOWLEDGMENT

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